

A contribution of stellar flares to the GRXE – based on MAXI observations –

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Abstract. Using unbiased observations of MAXI/GSC the potential contribution of stellar flares and CVs to GRXE luminosity is estimated in the energy range of 2~10 keV. Currently, a reasonable luminosity has been obtained extrapolating the number of stellar flares and that of CVs toward the Galactic ridge from those of the observed flares and CVs near the solar system. The ionized emission lines of Si to Fe are also simulated making the composite thermal spectrum which is based on MAXI observations of stellar flares and CVs. The present estimated result strongly supports a picture that the cumulative stellar flares contribute primarily to the GRXE in terms of the composite thermal spectrum with emission lines and secondary contribution is due to the thermal spectrum with high temperature from CVs.

1. Introduction to stellar flare observations by MAXI

MAXI, the first astronomical payload on JEM-EF of ISS, has monitored all sky X-ray sources since August 2009, including Galactic black holes, transient X-ray pulsars, low mass X-ray binaries, X-ray novae, X-ray bursts, stellar flares, CVs, Gamma-ray bursts, numerous AGNs and so on [1].

In this paper the detection of unexpected stellar flares has been pointed out in relation to a promising contribution to the GRXE [2] [3], despite insufficient statistics for the detection of stellar flares. With this in mind, a potential contribution to the GRXE is suggested, based on reasonable estimations of luminosity with emission line simulation from detected thermal spectra of stellar flares by MAXI/GSC. X-ray fluxes from CVs are detected as weak sources, but it is possible to obtain the total luminosity of CVs in the solar neighborhood in order to estimate the contribution to the GRXE.

The MAXI has two kinds of slit cameras, the GSC (Gas Slit Camera) and the SSC (Solid-state Slit Camera), both of which incorporate X-ray detectors consisting of gas proportional counters and X-ray CCDs [4]. The GSC can provide all-sky X-ray image every ISS orbit. The present observations of stellar flares are conducted by the GSC which is capable of detection with more sensitivity for stellar flares than that of any other ASMs.

The GSC detection threshold was set at 20 mCrab or less per ISS one orbit, hence the detected stellar flares were 23 for 21 months whose luminosities were distributed 1.6×10^{31} erg/s to 4.8×10^{33} erg/s [5]. Furthermore, the X-rays from Cataclysmic Variables (CVs) are generally weak with variable intensity and are occasionally produced with outburst. Currently, sources as weak as one mCrab or so are identified by making blinking images for one, three and seven days. Ten CVs are employed as effective ones to the GRXE.

2. Estimation of the contribution of stellar flares to the GRXE

Stellar flares from RS CVn's, Algol's, dMe's, young stellar objects and other flared stars have the common property that hot plasma grows up suddenly. The wide-ranging temperature distribution is capable of generating the various line emissions required for the GRXE. The temperature of these flares ranges from $kT =$ a few keV to ~ 10 keV. All the data are obtained from flares of known stars near the solar system by unbiased observations of MAXI/GSC.

CVs, especially magnetic CVs, generally produce thermal emission with higher temperature as $kT = 10 \sim 40$ keV [6]. The contribution of CVs to the GRXE is also estimated roughly in this paper.

2.1. Estimation of total luminosity of stellar flares to the GRXE

A total luminosity from 23 stellar flares for 21 months can be estimated by $\Sigma(\text{luminosity}[L] \times \text{efoldingtime}[\tau])$. The corrected result of the field of view as well as the live time and the energy band of 2~10 keV is obtained as $1.3(+0.3, -0.2) \times 10^{31}$ erg/s.

The stellar evolution is assumed to be equivalent to that of the neighboring solar system. The ratio of the stellar objects relative to the mass of the Galactic ridge region is obtained over the mass of the neighboring solar system, using the following two sources of data : (i) From Cox [7], the ratio of half the total mass of the Galaxy over the mass near the sun for the average distance, $d = 42$ pc from observed flared stars, is estimated to be 6.4×10^6 . (ii) From Revnivtsev et al [8], the ratio of stellar mass of the Galactic ridge and bulge over stellar mass near the sun within the average distance is estimated to be 6.9×10^6 .

Considering the factor of $\sim 6.5 \times 10^6$ anyway, the total luminosity of 2-10 keV can be obtained for the GRXE by multiplying the value of 1.3×10^{31} erg/s as

$$0.85(+0.20, -0.13) \times 10^{38} \text{ erg/s.} \quad (1)$$

In this estimation the following three uncertainties are not corrected. One uncertainty comes from flare duration time. Here an uncertainty factor for it is given as ϵ ; e.g., $\epsilon \sim 0.5$. Another uncertainty originates from the insufficient statistics which affect the result; e.g., the GM Mus reveals an extremely large value of $L \times \tau$, by one order of magnitude greater in comparison to the others. If this data were replaced tentatively by the second large value of $L \times \tau$, the result of (1) would be $\sim 0.37 \times 10^{38}$ erg/s. Considering these two uncertainties the result of the present estimation is expected as

$$(0.37 \sim 0.85)\epsilon \times 10^{38} \text{ erg/s.} \quad (2)$$

MAXI/GSC is considered as having a low luminosity cut-off due to instrumental capability. In order to estimate entire contribution of stellar flares it is necessary to evaluate the effect of low luminosity flares and instrumental cut-off in low luminosity.

It is considered that the luminosity function of some stellar flares including solar flares has a relation of $N(L) = kL^{-\alpha}$ for the number of flares *vs.* L (e.g., [9] [10]). If the power law index is assumed to be $\alpha = 2$ and the luminosity interval of $10^{30 \sim 34}$ erg/s is effective in the GRXE, it is possible to evaluate an instrumental cut-off of MAXI/GSC for the low luminosity to compare the observed data.

Thus obtained cut-off luminosity is around 1×10^{32} erg/s. Namely a correction factor for undetectable flares is estimated to be 2δ , corresponding to a low luminosity cut-off, where the factor, δ , is introduced as remaining uncertainty; e.g., $\delta \sim 1$. Therefore, multiplying 2δ to the result value of (2), the final luminosity for the GRXE is

$$(0.74 \sim 1.8)\epsilon\delta \times 10^{38} \text{ erg/s.} \quad (3)$$

2.2. Contribution of CVs and total luminosity from stellar flares and CVs

Preliminary results of CVs are given by Matsumura et al (in preparation). The total luminosity of 10 CVs observed in the solar neighborhood is effective to the GRXE to 21-month MAXI/GSC observations. The result of $(0.9 \sim 1.9) \times 10^{34}$ erg/s is obtained by estimation similar to previous section.

The average distance of CVs concerned is 282 pc. As estimated in the section 2.1, the ratio of stellar objects relative to the mass of the Galaxy was obtained over the neighboring solar system. This ratio resulted in $\sim 2 \times 10^3$. Finally the luminosity from stellar flares and CVs for GRXE is obtained as

$$(0.9 \sim 2.2)\epsilon\delta \times 10^{38} \text{ erg/s.} \quad (4)$$

This final value is consistent with the observed one, 2×10^{38} erg/s [2].

3. Emission lines from simulated composite thermal spectrum

MAXI/GSC cannot obtain precise thermal spectra from stellar flares. but it can determine temperature as single temperature model. A composite spectrum of observed stellar flares is created using X-ray flux f_i , temperature T_i and e-folding time τ_i of each flare as the equation,

$$F(E) = \Sigma F(E, T_i) \times f_i \times \tau_i / \Sigma (f_i \times \tau_i). \quad (5)$$

Figure 1 shows a composite spectrum obtained by the equation (5), where Suzaku response function with solar abundances is employed. Several emission lines as well as Fe 6.7 keV and 6.9 keV are seen in this figure.

Thin thermal spectra from magnetic CVs are also expected although complicated [6]. Nevertheless, the simulated spectrum of CVs is assumed to be a thin thermal spectrum with $kT=10$ keV. Since the contribution of CVs to the GRXE is $\sim 20\%$ as obtained in previous section 2.2, 20% thermal spectrum with $kT=10$ keV is added to the composite spectrum of stellar flares. A final composite spectrum thus obtained from stellar flares and CVs based on MAXI/GSC results is simulated as shown in Figure 1, where it is noted that a contribution lower than cut-off luminosity of stellar flares is neglected. Now equivalent widths of several emission lines are estimated by line fitting process through Suzaku analysis method. Thus obtained equivalent widths (eV unit) are ~ 25 , ~ 55 , ~ 400 and ~ 100 for $1.8 \sim 2$ keV (Si), $2.4 \sim 2.6$ keV (S), 6.7 keV (Fe), and $6.75 \sim 7.0$ keV (Fe), respectively.

The Fe 6.4 keV line is usually emitted by fluorescence. In deed CVs often produce considerable strong fluorescent 6.4 keV line. The 20% of average intensity of 6.4 keV from CVs obtained by Ezuka and Ishida [6] is tentatively

estimated as ~ 30 eV. Furthermore, Fe fluorescent line could be produced from interstellar gas irradiated by stellar flares. Similar mechanism to this is proposed by Bond and Matsuoka [11] to explain Fe fluorescent line in AGN. The equivalent width of 6.4 keV by this mechanism is also tentatively estimated as ~ 20 eV.

The equivalent widths of several emission lines in this section are slightly weak in comparison to the observed ones [12] [13]. Nevertheless, considering the present rough estimation it is strongly suggested that various emission lines are produced mainly stellar flares and secondarily from CVs.

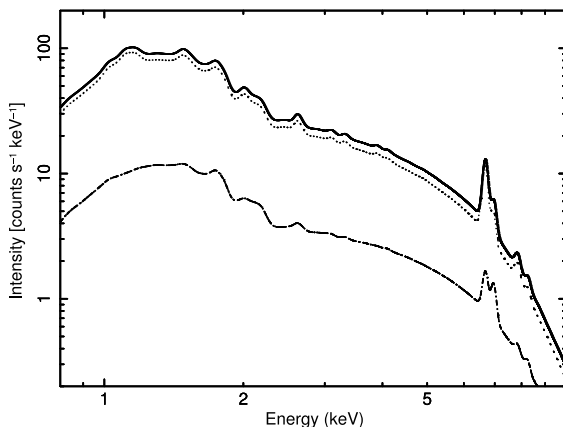


Figure 1. A simulated composite spectrum for the GRXE. A chain line is a thermal spectrum with $kT=10$ keV for CVs, where the intensity level is 20% of a composite spectrum of stellar flares. A dotted line is a composite spectrum of cumulative stellar flares. A solid line is a total composite spectrum consisting of stellar flares and CVs. In this spectrum Suzaku XIS response function is employed, while solar abundances are assumed.

4. Conclusion

This paper is not aimed at achieving a complete explanation of the GRXE by stellar flares and CVs, but it is to notice that a major of the GRXE is produced from stellar flares and the second contribution is due to CVs. This conclusion is based on the MAXI/GSC unbiased observations although statistics and detectability analysis are not yet conclusive. However, further MAXI/GSC observations will make those better in future, while the assumption will be improved by progress of stellar flare physics. In any case the present essential conclusion would not be changed even in future (Matsuoka et al in preparation).

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